PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

**(51) International Patent Classification** 6 :
**F03D 7/04, 11/00**

**A1**

**(11) International Publication Number:** **WO 99/36695**

**(43) International Publication Date:** 22 July 1999 (22.07.99)

**(21) International Application Number:** PCT/DK99/00020

**(22) International Filing Date:** 14 January 1999 (14.01.99)

**(30) Priority Data:**
0046/98 14 January 1998 (14.01.98) DK

**(71) Applicant** *(for all designated States except US)*: DANCONTROL ENGINEERING A/S [DK/DK]; Italiensvej 3, DK-8450 Hammel (DK).

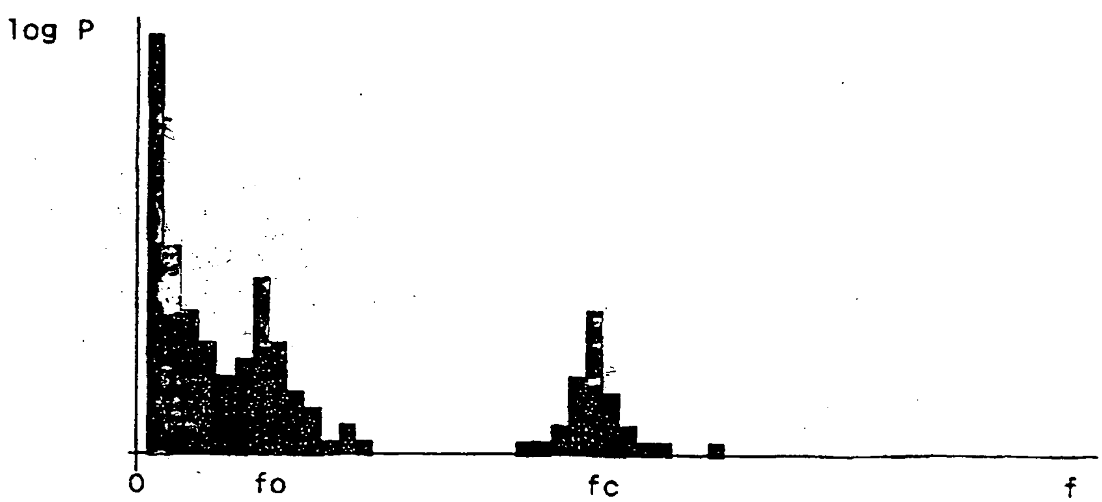
**(72) Inventor; and**
**(75) Inventor/Applicant** *(for US only)*: GARNAES, Svend [DK/DK]; Klampenborgvej 3, DK-5700 Svendborg (DK).

**(74) Agent:** PLOUGMANN, VINGTOFT & PARTNERS A/S; Sankt Annæ Plads 11, P.O. Box 3007, DK-1021 Copenhagen K (DK).

**(81) Designated States:** AL, AM, AT, AT (Utility model), AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, CZ (Utility model), DE, DE (Utility model), DK, DK (Utility model), EE, EE (Utility model), ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SK (Utility model), SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

**Published**
*With international search report.*
*Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.*
*In English translation (filed in Danish).*

**(54) Title:** METHOD FOR MEASURING AND CONTROLLING OSCILLATIONS IN A WIND TURBINE




**(57) Abstract**

The invention relates to a method for measuring and controlling oscillations in a wind turbine wherein the wind turbine control system is adapted by means of spectrum analysis, to determine the existence and amplitude of vibrations of the wind turbine rotor blades and/or other structural vibrations on the basis of existing sensor/transducer signals relating to the characteristics of the electrical power output. The control system of the wind turbine is adapted to attenuate the oscillations before they reach an unacceptable level, and thereafter to cause the wind turbine to resume normal operation.

*FOR THE PURPOSES OF INFORMATION ONLY*

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| AL | Albania | ES | Spain | LS | Lesotho | SI | Slovenia |
| AM | Armenia | FI | Finland | LT | Lithuania | SK | Slovakia |
| AT | Austria | FR | France | LU | Luxembourg | SN | Senegal |
| AU | Australia | GA | Gabon | LV | Latvia | SZ | Swaziland |
| AZ | Azerbaijan | GB | United Kingdom | MC | Monaco | TD | Chad |
| BA | Bosnia and Herzegovina | GE | Georgia | MD | Republic of Moldova | TG | Togo |
| BB | Barbados | GH | Ghana | MG | Madagascar | TJ | Tajikistan |
| BE | Belgium | GN | Guinea | MK | The former Yugoslav Republic of Macedonia | TM | Turkmenistan |
| BF | Burkina Faso | GR | Greece | | | TR | Turkey |
| BG | Bulgaria | HU | Hungary | ML | Mali | TT | Trinidad and Tobago |
| BJ | Benin | IE | Ireland | MN | Mongolia | UA | Ukraine |
| BR | Brazil | IL | Israel | MR | Mauritania | UG | Uganda |
| BY | Belarus | IS | Iceland | MW | Malawi | US | United States of America |
| CA | Canada | IT | Italy | MX | Mexico | UZ | Uzbekistan |
| CF | Central African Republic | JP | Japan | NE | Niger | VN | Viet Nam |
| CG | Congo | KE | Kenya | NL | Netherlands | YU | Yugoslavia |
| CH | Switzerland | KG | Kyrgyzstan | NO | Norway | ZW | Zimbabwe |
| CI | Côte d'Ivoire | KP | Democratic People's Republic of Korea | NZ | New Zealand | | |
| CM | Cameroon | | | PL | Poland | | |
| CN | China | KR | Republic of Korea | PT | Portugal | | |
| CU | Cuba | KZ | Kazakstan | RO | Romania | | |
| CZ | Czech Republic | LC | Saint Lucia | RU | Russian Federation | | |
| DE | Germany | LI | Liechtenstein | SD | Sudan | | |
| DK | Denmark | LK | Sri Lanka | SE | Sweden | | |
| EE | Estonia | LR | Liberia | SG | Singapore | | |

# METHOD FOR MEASURING AND CONTROLLING OSCILLATIONS IN A WIND TURBINE

The present invention relates to a method for measuring and controlling oscillations in a wind turbine coupled directly to a power mains, voltage and/or current being measured at the mains connection and other values being optionally derived therefrom, such as apparent power, real power, reactive power, power factor, and $\cos(\varphi)$.

The development of wind turbines leads to increasingly bigger turbines with increasing hub heights and rotor diameters. This creates a number of mechanical difficulties caused by the correspondingly lower natural resonance frequencies and attenuations of the structures used.

Furthermore, certain rotor blades in common use show a tendency to form a complex pattern of rotor blade oscillations of great amplitude under certain meteorological conditions. This exposes the rotor blades to unacceptable dynamic loads reducing their time of life and endangering the wind turbine safety.

It is essential for the structural safety of the wind turbine and thus also for human safety to be able to detect both oscillations of the wind turbine rotor blades and other structural oscillations of the wind turbine and to be able to stop these oscillations, e.g. by a temporary wind turbine standstill or in any other way.

A general wind turbine standstill under meteorological conditions that appear to facilitate the oscillation phenomena is not a practicable solution as it would be detrimental to the annual output of the wind turbine. It is therefore desirable to be capable of detecting the presence or absence of the oscillation phenomena and to be capable of adjusting the wind turbine control means so as to stop any occurring oscillation phenomenon so that the wind turbine may resume normal operation once the oscillation phenomenon has ceased.

Certainly all wind turbines have been provided with a device capable of detecting heavy oscillations and bringing the turbine to a standstill by interacting with the wind turbine emergency stop circuit. However, this device is primarily designed to ensure stopping the wind turbine in case of a sudden rotor unbalance such as by loss of a

blade tip or in case of structural damage to the rotor following a lightning stroke. This prior art device cannot detect rotor blade oscillations or tower oscillations until they have reached an amplitude which presents an immediate danger to the wind turbine. Further, in the case of rotor blade oscillations even if the oscillation phenomenon of a single blade reaches a harmful amplitude, the resulting vibration level as measured e.g. at the wind turbine nacelle is relatively modest as the phenomenon generally comprises oscillations in opposite phase on two out of three rotor blades. Therefore such a device is not suitable for detecting such a harmful situation.

Further, this prior art device is generally incapable of making the wind turbine resume normal operation once the oscillations have ceased, since the device is incorporated as a part of the emergency stop circuit of the wind turbine.

Finally, self-contained vibration guards are known that may be incorporated in wind turbines. These guards permit detecting the presence of e.g. oscillations at a modest amplitude so that the dynamic load on the rotor blades can be kept within acceptable limits provided that the turbine can be stopped at the command of the vibration guard. However, these self-contained units are normally also incorporated in the emergency stop circuit of the wind turbine and thus also cannot bring the wind turbine into normal operation once the oscillations have ceased.

For the purpose of wind turbine approval, it is also desirable that detection and countermeasures against oscillation phenomena are effected at a modest oscillation amplitude by the wind turbine control system itself not depending upon external devices.

It is an object of the present invention to provide a method for detecting on the basis of existing measurement signals the existence of wind turbine oscillations and for attenuating these oscillations by means of the wind turbine control system.

This object is achieved by a method of the type mentioned initially, in which a spectrum analysis is performed of one or more of the measured values or any values derived therefrom, and wind turbine oscillation amplitudes are determined on the basis of the result of the spectrum analysis, and when the determined amplitude exceeds a

certain value, countermeasures are taken by the wind turbine control system to reduce the amplitude of the oscillations.

This permits detection of even minor vibrations or oscillations without incorporation of external devices in the wind turbine by exploitation of the fact that the vibrations or oscillations lead to variations in the electrical measurements already being made on the wind turbine or values derived therefrom, and permits using the result of the detection to attenuate the detected vibrations or oscillations by means of the wind turbine control system.

The dependent claims define appropriate embodiments of the method according to the invention. Particularly the dependent claims 4-10 define appropriate methods of counteracting for reducing the amplitude of the detected oscillations relating to the particular type of control system provided in a wind turbine.

The invention will be further explained in the following referring to Fig. 1 which illustrates a spectrum analysis of a recorded measurement of a wind turbine.

A wind turbine control system is always adapted to make a number of measurements at the mains connection of the turbine. The measurements are made partly for operational reasons and partly for datalogging and statistics relating to the operation of the wind turbine. For that purpose the wind turbine control system is provided with a number of transducers for measuring voltage and current of the phases of the mains connection. Based on these primary measurements of voltage and current, the control system can calculate further secondary mains data, e.g. apparent power, real power, reactive power, power factor or cos(φ).

Rotor blade oscillations lead to vibrations in the nacelle and rotor shaft of the wind turbine. Also in case of oscillations in opposite phase on two out of three rotor blades, vibrations can be measured in the nacelle and this may be caused by an asymmetry (a non-linear elasticity) caused by the oscillation amplitude involved. Thus the rotor shaft torque will also comprise a component generated by rotor oscillations.

Since the rotor blade oscillations generate a component in the torque of the rotor shaft, such component will also appear in the generator shaft torque and in a wind turbine with a generator coupled directly to the mains. It will therefore also appear in the primary measurements of current and/or voltage and in all the secondary mains data derived from the primary measurement values.

According to the invention, the wind turbine control system performs a spectrum analysis of one or more of these sets of data and an averaging of a number of spectra. Thereby the fluctuations of the generator shaft torque generated by the oscillation phenomena will appear as a column or a narrow band of columns in the spectrum around the characteristic frequency $f_c$ of the oscillations as shown in Fig. 1. The amplitude of the column in the spectrum indicates to the control system the amplitude of oscillations of the rotor blades and thereby provides a basis for decisions on the wind turbine operation.

Axial tower oscillations, i.e. oscillations in the longitudinal direction of the main shaft, will create fluctuations in the apparent wind velocity and thereby also fluctuations in the rotor and generator shaft torques. Like rotor blade oscillations such fluctuations can be detected in the primary measurement data and in the secondary measurement data derived from the primary measurement data. By a spectrum analysis, the fluctuations will appear as a column or a narrow band of columns in the spectrum at the characteristic frequency $f_0$ as shown in Fig. 1. The amplitude of this column indicates the amplitude of the axial tower oscillations and thereby provides a basis for decisions on the wind turbine operation.

Depending on the type of the wind turbine and its equipment the control system according to the invention may operate in various ways. A first type of countermeasure seeks to attenuate the oscillation phenomena by changing the rotational speed of the rotor, while a second type seeks to change the oscillation phenomena by changing the dynamic load of the wind turbine.

For a wind turbine directly coupled to the mains, the first type of countermeasures comprises the application of brakes. Whether the brakes will be applied until standstill depends on the characteristics of the brake system used. Certain types of tip brakes

can only be reset at rotor standstill, so if such types are used, the rotor must be brought to a standstill before restart. However, if tip brakes can be reset during rotation, the control system can perform a restart "on the fly" of the wind turbine once the control system has detected that the oscillations have decayed.

Utilisation of a mechanical disk brake is possible in countermeasures of the first type, but such a utilisation is believed to lead to unacceptable wear of the brake. If the wind turbine is provided with an electrically controllable brake (retarder), this may advantageously be used in the control, always permitting a restart "on the fly". Finally, in wind turbines of the active stall type the entire blade profile is used as a brake, and in a wind turbine of this type with a control system according to the present invention it is possible to restart "on the fly".

The second type of countermeasure wherein the control system counteracts by changing the dynamic load may in stall controlled wind turbines with a fixed pitch angle comprise the control system introducing a yaw angle error until the oscillation phenomena disappear, whereupon the turbine resumes normal operation without yaw angle error.

The dynamic load can be changed in active stall wind turbines by changing the blade pitch angle in a negative direction until the oscillation phenomena disappear, whereupon the turbine resumes normal operation at the currently required pitch. For this type of turbine, the control system may also utilize introduction of a yaw angle error, if necessary.

CLAIMS

1. A method for measuring and controlling oscillations in a wind turbine coupled directly to a power mains, voltage and/or current being measured at the mains connection, and other values optionally being derived therefrom, such as apparent power, real power, reactive power, power factor, and cos(φ), characterized by the steps of

- performing a spectrum analysis of one or more of the measured values or values derived therefrom,

- determining the amplitude of wind turbine oscillations based on the spectrum analysis and

- attenuating the oscillations by countermeasures performed by the wind turbine control system, if a determined amplitude of oscillations exceeds a predetermined value.

2. A method according to claim 1, further comprising the step of averaging a number of spectra from the spectrum analysis.

3. A method according to claim 1, wherein the oscillations, the amplitudes of which are determined, are rotor blade oscillations and/or axial tower oscillations.

4. A method according to claims 1, 2 or 3, wherein the step of attenuating comprises reducing the rotational speed of the rotor.

5. A method according to claim 4, wherein the step of attenuating comprises braking until standstill followed by restarting.

6. A method according to claim 4, wherein the step of attenuating comprises braking until the amplitude of the oscillations is reduced to less than a predetermined value.

7. A method according to claims 1, 2 or 3, wherein the step of attenuating comprises reducing the dynamic load.

8. A method according to claim 7, wherein the wind turbine is a stall controlled wind turbine with a fixed pitch angle, and the step of attenuating comprises subjecting a yaw angle error to the wind turbine until the oscillation amplitude has decayed below a predetermined value whereupon the wind turbine resumes normal operation without yaw angle error.

9. A method according to claim 7, wherein the wind turbine is an active stall controlled wind turbine with a variable pitch angle, wherein the step of attenuating comprises changing the blade pitch angle in a negative direction until the oscillation amplitude has decayed below a predetermined value whereupon the wind turbine resumes normal operation at the currently required pitch angle.

10. A method according to claim 9, wherein the step of attenuating further comprises subjecting a yaw angle error to the wind turbine until the oscillation amplitude has been decayed below a predetermined value, whereupon the wind turbine resumes normal operation without yaw angle error.

SUMMARY

The invention relates to a method for measuring and controlling oscillations in a wind turbine wherein the wind turbine control system is adapted to determine the existence and amplitude of vibrations of the wind turbine rotor blades and/or other structural vibrations on the basis of existing sensor/transducer signals.

The control system of the wind turbine is adapted to attenuate the oscillations before they reach an unacceptable level, and thereafter to cause the wind turbine to resume normal operation.

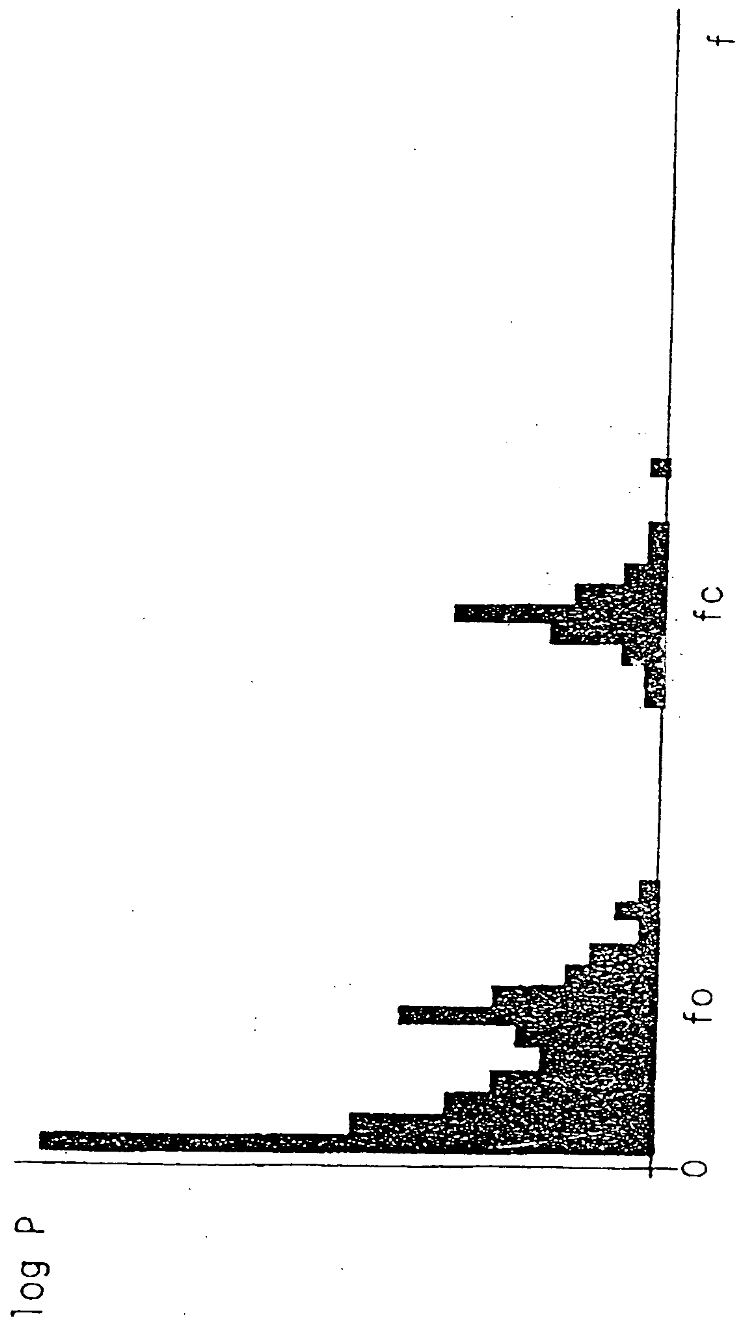



Figure 1/1

# INTERNATIONAL SEARCH REPORT

International Application No
PCT/DK 99/00020

**A. CLASSIFICATION OF SUBJECT MATTER**
IPC 6 F03D7/04 F03D11/00

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 F03D F01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category ° | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | US 4 435 647 A (HARNER KERMIT I ET AL) 6 March 1984<br>see abstract<br>see column 1, line 39 - line 45<br>see column 2, line 27 - line 43 | 1 |
| A | US 4 160 170 A (HARNER KERMIT I ET AL) 3 July 1979<br>see abstract<br>see column 6, line 51 - line 57; figure 2 | 1 |
| A | US 5 140 856 A (LARSEN ORLA W) 25 August 1992<br>see column 8, line 65 - column 9, line 6 | 1 |
| A | GB 2 096 770 A (STANDARD TELEPHONES CABLES LTD) 20 October 1982<br>see abstract | 1 |

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 20 May 1999 | 04/06/1999 |

| Name and mailing address of the ISA | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,<br>Fax: (+31-70) 340-3016 | Criado Jimenez, F |

1

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

| Category ° | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | US 5 614 676 A (DUTT WILLIAM R ET AL)<br>25 March 1997<br>see abstract; figures<br>----- | 1 |

1

# INTERNATIONAL SEARCH REPORT

rmation on patent family members

ter onal Application No
CT/DK 99/00020

| Patent document cited in search report | | Publication date | Patent family member(s) | | | Publication date |
|---|---|---|---|---|---|---|
| US 4435647 | A | 06-03-1984 | AU | 552913 | B | 26-06-1986 |
| | | | BR | 8301456 | A | 29-11-1983 |
| | | | CA | 1186393 | A | 30-04-1985 |
| | | | DE | 3308564 | A | 13-10-1983 |
| | | | DK | 136683 | A | 03-10-1983 |
| | | | FI | 831031 | A | 03-10-1983 |
| | | | FR | 2524570 | A | 07-10-1983 |
| | | | GB | 2117934 | A,B | 19-10-1983 |
| | | | IN | 158266 | A | 11-10-1986 |
| | | | JP | 58178885 | A | 19-10-1983 |
| | | | NL | 8301059 | A | 01-11-1983 |
| | | | SE | 8301552 | A | 03-10-1983 |
| | | | ZA | 8301632 | A | 30-11-1983 |
| US 4160170 | A | 03-07-1979 | CA | 1120537 | A | 23-03-1982 |
| | | | DE | 2922972 | A | 03-01-1980 |
| | | | DK | 243579 | A | 16-12-1979 |
| | | | FR | 2428749 | A | 11-01-1980 |
| | | | GB | 2023237 | A,B | 28-12-1979 |
| | | | SE | 444599 | B | 21-04-1986 |
| | | | SE | 7905005 | A | 16-12-1979 |
| US 5140856 | A | 25-08-1992 | AU | 9121791 | A | 25-06-1992 |
| | | | WO | 9209871 | A | 11-06-1992 |
| GB 2096770 | A | 20-10-1982 | SE | 8202319 | A | 15-10-1982 |
| US 5614676 | A | 25-03-1997 | AU | 1516197 | A | 11-09-1997 |
| | | | BR | 9701140 | A | 22-09-1998 |
| | | | CA | 2176992 | A | 09-09-1997 |
| | | | CZ | 9700692 | A | 14-01-1998 |
| | | | EP | 0794420 | A | 10-09-1997 |
| | | | HU | 9700559 | A | 29-12-1997 |
| | | | JP | 10010015 | A | 16-01-1998 |
| | | | PL | 318751 | A | 15-09-1997 |